PAVEMENT DESIGN GUIDE
(2007 Revision)

For Projects
Off The National Highway System
less than 20,000,000 ESAL'S,
less than 15,000 ADT,
and less than 20% Trucks

DIVISION OF HIGHWAY DESIGN
PAVEMENT BRANCH

KENTUCKY TRANSPORTATION CABINET

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Background and Scope

This guide should be used for new construction or full-depth reconstruction projects only. **This guide provides a methodology for the structural design of pavements for projects off the National Highway System, with less than 20,000,000 ESAL's, less than 15,000 ADT, and less than 20% trucks.** The methodology presented has roots in both the *AASHTO Guide For Design of Pavement Structures* and also the Kentucky mechanistic-empirical pavement design systems which are used for the structural design of pavements in Kentucky. The Kentucky design procedures are outlined in the University of Kentucky Research Reports UKTRP-81-17 *Design Guide for Bituminous Concrete Pavement Structures* and UKTRP-84-3 *Thickness Design Curves for Portland Cement Concrete Pavements*.

The procedure presented uses an AASHTO structural number concept to define structural requirements of the pavement section. However, the minimum required structural number has been determined on the basis of the Kentucky mechanistic-empirical pavement design procedure. The structural capacity of the subgrade soil has been defined in terms of a California Bearing Ratio (CBR) determined by the current Kentucky Method (Note: The Kentucky Method for CBR Tests is different from the AASHTO and ASTM Methods for CBR Tests). The fatigue requirements of the pavement structure used in this guide are based on Equivalent 18,000 lb Axle Loads (ESAL's) as determined using load equivalency factors developed for the Kentucky mechanistic-empirical pavement design procedure. (Note: Kentucky load equivalency factors are different from AASHTO load equivalency factors.)

This guide is intended to be self-sufficient with the exception of: (1) Forecasts for ESAL's; (2) Recommended design CBR; (3) Special Notes and Special Provisions not included in the Standard Specifications or Standard Drawings; and (4) Pavement policy guidelines which may be subject to periodic modifications such as guidelines for surface type selection. This guide includes a discussion relating to ESAL's and the prediction of ESAL's. Also included is a discussion relating Kentucky CBR with typical soil types and provides general guidelines for estimating a design CBR. A listing of Special Notes and Special Provisions most typically used in pavement design is included in the Appendix of this guide. Applicable policy documents are also included in an Appendix.

Also included are discussions defining the responsibilities of the roadway designer for documentation of pavement design computations and related submittals. The Guide also includes discussions regarding the role of the Pavements Branch, Division of Highway Design for providing assistance in the implementation of this guide.

Subgrade Strength

The material property used to characterize the roadbed soil for pavement design in this guide is the Kentucky CBR (California Bearing Ratio). Details for testing for the Kentucky CBR are presented in the current Edition of the Kentucky Methods (KM 64-501).

Subgrades typically are constructed of soils from roadway excavation or borrow. However, subgrades also may be composed of rock. Rock subgrades may exclude shale, include shale with other rock types, or be constructed entirely of shale. A Rock roadbed is utilized for the top two feet of the roadway when sufficient quantities of suitable rock are available from roadway excavation.

Typically, CBR tests and soil classification tests will be performed by the Division of Structural Design, Geotechnical Branch. Typically, the design CBR for soil subgrades will be recommended as the lowest value from laboratory tests (unless there is an isolated value). For larger projects with twenty or more CBR tests, the design CBR will be selected statistically as the 90th percentile value. Higher design CBRs may be recommended for projects involving rock roadbed or bank gravel.

Shales are cemented or non-cemented sedimentary deposits of various chemical compositions in which the constituent particles are 0.75 mm in diameter and include siltstone, claystone, and mudstone. Shales are classified according to Slake Durability Index (SDI) results. Sedimentary shale deposits are frequently inter-bedded with thin sections of carbonates or arenaceous (sandy) partings that can produce distorted SDI values. Jar slake tests typically are performed to provide additional information about rock disintegration to compare with SDI results.

The tables below illustrate typical ranges of Estimated CBR values for a range of material types.

MATERIAL	ESTIMATED CBR
Rock (limestone, durable sandstone, durable shale, non-durable sandstone)	7 to 11
Rock (non-durable shale)	2 to 5
Bank Gravel	6 to 9
Soil and/or other shale mixtures	1 to 5

The results of slaking tests are used to classify shales as “durable” or “non-durable. Non-durable shales are subdivided into classes for design purposes only. Classification of shales and typical correlations with Jar Slake Test results are listed in the table below.

SHALE CLASSIFICATION	RANGE OF SLAKE DURABILITY	SLAKING CATEGORY
Durable Shale	≥ 95	6
Nondurable Shales		
Class I	80 to 94	4 or 5
Class II	50 to 79	3 or 4
Class III	≤ 49	1 or 2

The design CBR also may be estimated on the basis of soil classifications. The following table may be used to estimate design CBR.

DESCRIPTION		ESTIMATED CBR
FINE GRAINED SOILS		
High Compressibility (Liquid Limit Greater Than 50)		
Peat, Organic Soils	(PT)	1
Fat Organic Clays	(OH)	1 to 2
Fat Clays	(CH)	2 to 4
Micaceous Clays	(MH)	2 to 4
Low Compressibility (Liquid Limit Less Than 50)		
Organic Silts or Lean Organic Clays	(OL)	3 to 5
Lean Clays, Sandy Clays, or Gravelly Clays	(CL)	3 to 5
Silts, Sandy Silts, Gravelly Silts	(ML)	3 to 5
COARSE GRAINED SOILS		
Sand and Sandy Soils		
Clayey Sand, Clayey Gravelly Sand	(SC)	5 to 7
Silty Sand, Silty Gravelly Sand	(SM)	5 to 7
Sand or Gravelly Sand (uniformly graded)	(SU)	5 to 7
Sand or Gravelly Sand (poorly graded)	(SP)	5 to 7
Sand or Gravelly Sand (well graded)	(SW)	5 to 7
Gravel and Gravelly Soils		
Clayey Gravel or clayey sandy gravel	(GC)	5 to 7
Silty Gravel or silty sandy gravel	(GM)	5 to 7
Gravel or Sandy Gravel (uniformly graded)	(GU)	5 to 7
Gravel or Sandy Gravel (poorly graded)	(GP)	5 to 7
Gravel or Sandy Gravel (well graded)	(GW)	5 to 7

*A CBR of 3 can be assumed for most conditions in Kentucky unless the particular District has a history of poor load bearing soils. These locations can use an assumed CBR of 1.

Subgrade Stabilization

The majority of pavements constructed in Kentucky are constructed on fine-grained soils. Approximately 85 percent of the soils consist of clay and silt. When first compacted, these fine-grained soils usually have sizeable bearing strength. If pavements are constructed immediately after compaction of fine-grained soils, major problems typically will not be encountered when placing and compacting layers of paving materials. Problems arise, however, when surface and subsurface water penetrates compacted fine-grained soils. Water from rainfall, snow melt, and groundwater seepage enters the fine grained soil subgrades, causing swelling, and producing a loss of bearing capacity in the subgrade. The most susceptible, adverse period occurs when a fine grained soil subgrade has been exposed to the wetting conditions of winter and early spring. During periods before paving, rutting may develop in the softened subgrade. This may slow or even halt construction traffic. This also may impede compaction of the lifts of the pavement structure, resulting in a weaker pavement structure than initially designed. Therefore, the weakened subgrade not only slows construction but also limits the long-term life of the pavement structure.

Recent experience in Kentucky has demonstrated the benefits of stabilized subgrades for providing a stable platform for placement of pavement layers and also for extending the life of the pavement structure. Methods for stabilization may be characterized into two broad categories: mechanical stabilization and chemical stabilization.

Mechanical Stabilization

Methods for mechanical stabilization of subgrade soils include the following approaches:

a. Controlling subgrade density-moisture,
b. Undercutting poor materials and back-filling with granular materials,
c. Proof rolling and re-rolling of the subgrade,
d. Using granular layers,
e. Using granular layers reinforced with geofabrics, and
f. Using granular layers reinforced with geogrids.

The above techniques for mechanical stabilization of subgrade soils have been used in Kentucky to varying degrees. Laboratory studies of blending stone aggregate into soil subgrades have shown that mixing stone aggregate with subgrade soils of minimum clay content is effective in improving the bearing capacity of the subgrade soil. Conversely, if the percent finer than 0.002 mm-particle size is greater than 15 percent, there is a reduction in bearing strength. Therefore, mechanical stabilization by adding stone aggregate to the soil may be ineffective in soils with high clay content. Geofabrics and geogrids also have been used in Kentucky. These have been demonstrated to improve the bearing capacity of granular bases and granular or coarse grained subgrade soils. However, the use of geogrids with fine-grained soils having high clay contents should be approached with greater caution.

Chemical Stabilization

Chemical stabilization of subgrade soils was used sparingly in Kentucky prior to the mid-1980's. Stabilization prior to the mid-1980s was with Portland cement. Since then, there has been much greater emphasis on the use of the chemical stabilization of subgrades.

Commercially available stabilizers have included hydrated lime and cement. Both have been demonstrated as effectively stabilizing subgrade soils as stable paving platforms and are believed to contribute to extending the fatigue life of pavement structures. Portland cement has been demonstrated to be more effective at stabilizing more granular, coarse grained subgrades. Hydrated lime has been demonstrated to be more effective at stabilizing fine-grained soils with high clay content. Other by-product materials such as lime or cement kiln dust have been used experimentally for soil stabilization.

Most subgrade soils having a CBR 6 or less are recommended for stabilization. *Chemical stabilization should only be used if recommended by the Division of Structural Design Geotechnical Branch.* The stabilized subgrade soil layer typically is treated as both an improved subgrade layer serving as a stable paving platform as well as a structural layer for extending the life of the pavement structure. Typically, blending about 5-6 % of hydrated lime or Portland cement by dry weight with the subgrade soil will result in a stable paving platform and structurally significant layer of the pavement system.

Analyses of chemically stabilized subgrade soils have indicated very high strengths of the stabilized layers (much greater than a CBR 7). The layer coefficients associated with these structural parameters to be used in this design guide will be defined elsewhere in this document. *Chemical stabilization should be applied from shoulder break to shoulder break in the typical section.* (Shoulder break is defined as the intersection of the shoulder slope and the ditch slope.)

Analyses of mechanically modified subgrades have indicated varying strengths of stabilized layers dependent upon the characteristics of the soil being modified. Blending aggregate with coarse-grained granular soils may increase the strengths of the stabilized layers to strengths similar to that of aggregate bases. However, blending aggregate with fine-grained soils with high clay contents may do nothing to increase the bearing capacity of the soil or at best will be minimally effective. The layer coefficients associated with mechanically modified subgrade soils will be defined elsewhere in this guide.

Recommended Subgrade Stabilization Procedures (See Design Memo No. 17-04)

Subgrades with CBR values of 6 or less should be considered for stabilization. The Division of Structural Design Geotechnical Branch will determine if stabilization is required and may suggest the appropriate treatment method. The following stabilization guidelines will be used to determine the method of stabilization and will be considered equivalent for pavement design purposes:

CBR 1 to 6: Option 1 – Eight (8) inches (minimum) of chemical stabilization using cement or lime, as applicable.

Option 2 - Twelve (12) inches (minimum) of coarse aggregate (2’s, 3’s, or 23’s) wrapped with a Type IV Geotextile Fabric.

CBR > 4: Option 3 - An additional three (3) inches of Dense Graded or Crushed Stone Base (minimum 7 inches total) with a Geogrid and a Type IV Geotextile Fabric**.

**Geogrid base course can, but will not always function as a separator between the subgrade soil and the aggregate base course. A Type IV Geotextile fabric should be placed between the subgrade soil and geogrid when the filter criteria shown below is not satisfied. This criteria will be evaluated by the Geotechnical Branch when considering the use of geogrid and the appropriate recommendation will be included in the Geotechnical report.

Criteria for Use of Fabric Separator

- Base course is not an effective filter to prevent the migration of fines. Both filter criteria listed below must be satisfied.

Filter Criteria

$$\frac{D_{15}\text{ (filter)}}{D_{85}\text{ (soil)}} < 5 \qquad \frac{D_{50}\text{ (filter)}}{D_{50}\text{ (soil)}} \leq 25$$

When the CBR for the subgrade is greater than a CBR of 4 and less than or equal to a CBR of 8, the following Tables 1 and 1a of ESALs, CBRs and Pavement Structural Numbers may be used to determine the thickness of pavement required when a geogrid is used for stabilization of the aggregate base. These tables have been derived from analyses of literature associated with TENSAR Type II (BX1200) Geogrid and the TENSAR Type I (BX1100) Geogrid. The physical requirement for the geogrids are outlined in the *Special Note For Geogrid Used for Reinforcement of Subgrade and Aggregate Base Courses* (10B). This Special Note shall be included in the project proposal.

The following tables of structural numbers may be used instead of the structural numbers listed in Table 2 provided the thickness of aggregate base is at least seven (7) inches. Geogrids used must meet specifications as presented in the Standard Specifications or in other applicable documents (Special Provisions, Special Notes, etc.).

Note: The first number is for Type I Geogrid. The numbers in parentheses are for Type II Geogrid

TABLE 1. Structural Numbers for use with Geogrids

ESALs	**CBR**				
	4	**5**	**6**	**7**	**8**
10,000	N/A	N/A	N/A	N/A	N/A
25,000	2.63 (N/A)	N/A	N/A	N/A	N/A
50,000	2.98**(2.65)**	2.75 (N/A)	2.55 (N/A)	N/A	N/A
75,000	3.20**(2.86)**	2.95**(2.63)**	2.76 (N/A)	2.58 (N/A)	N/A
100,000	3.34**(2.99)**	3.10**(2.77)**	2.89**(2.59)**	2.71 (N/A)	2.58 (N/A)
250,000	3.79**(3.42)**	3.55**(3.18)**	3.36**(2.99)**	3.16**(2.83)**	3.02**(2.69)**
500,000	4.13**(3.71)**	3.90**(3.52)**	3.68**(3.31)**	3.50**(3.12)**	3.34**(2.99)**
750,000	4.37**(3.95)**	4.10**(3.73)**	3.90**(3.52)**	3.71**(3.34)**	3.54**(3.17)**
1,000,000	4.53**(4.07)**	4.25**(3.82)**	4.03**(3.63)**	3.83**(3.46)**	3.68**(3.30)**
2,000,000	4.97**(4.45)**	4.67**(4.18)**	4.43**(3.99)**	4.19**(3.75)**	4.02**(3.61)**
3,000,000	5.25**(4.70)**	4.94**(4.43)**	4.67**(4.18)**	4.44**(3.99)**	4.23**(3.80)**
4,000,000	5.46**(4.88)**	5.15**(4.62)**	4.87**(4.37)**	4.60**(4.12)**	4.38**(3.96)**
5,000,000	5.62**(5.01)**	5.30**(4.74)**	5.02**(4.50)**	4.74**(4.25)**	4.53**(4.07)**
6,000,000	5.75**(5.13)**	5.43**(4.88)**	5.12**(4.60)**	4.87**(4.37)**	4.66**(4.17)**
7,000,000	5.88**(5.26)**	5.53**(4.93)**	5.23**(4.68)**	4.97**(4.45)**	4.74**(4.25)**
8,000,000	5.98**(5.36)**	5.62**(5.01)**	5.32**(4.76)**	5.07**(4.55)**	4.86**(4.36)**
9,000,000	6.10**(5.48)**	5.74**(5.12)**	5.40**(4.83)**	5.16**(4.63)**	4.93**(4.42)**
10,000,000	6.17**(5.55)**	5.81**(5.19)**	5.51**(4.91)**	5.23**(4.68)**	5.00**(4.48)**
11,000,000	6.25**(5.56)**	5.88**(5.26)**	5.58**(4.97)**	5.30**(4.74)**	5.07**(4.55)**
12,000,000	6.33**(5.71)**	5.95**(5.33)**	5.62**(5.02)**	5.38**(4.81)**	5.12**(4.60)**
13,000,000	6.40**(5.78)**	6.02**(5.40)**	5.69**(5.07)**	5.43**(4.84)**	5.17**(4.64)**
14,000,000	6.46**(5.84)**	6.08**(5.46)**	5.75**(5.13)**	5.46**(4.88)**	5.25**(4.70)**
15,000,000	6.53**(5.91)**	6.12**(5.50)**	5.81**(5.19)**	5.53**(4.93)**	5.30**(4.74)**
16,000,000	6.56**(5.94)**	6.18**(5.56)**	5.87**(5.25)**	5.59**(4.98)**	5.33**(4.77)**
17,000,000	6.63**(6.01)**	6.24**(5.62)**	5.91**(5.29)**	5.62**(5.01)**	5.39**(4.82)**
18,000,000	6.69**(6.07)**	6.27**(5.65)**	5.97**(5.35)**	5.68**(5.03)**	5.45**(4.86)**
19,000,000	6.74**(6.12)**	6.33**(5.71)**	6.01**(5.39)**	5.74**(5.12)**	5.48**(4.90)**
20,000,000	6.77**(6.15)**	6.38**(5.76)**	6.04**(5.42)**	5.75**(5.13)**	5.52**(4.92)**

Equivalent Single Axle Loads

Traffic information is required by the pavement designer to associate the damaging effects of the applications of an axle of any load applied to the pavement. The term Equivalent Single Axle Load (ESAL) is used in pavement design methodologies to describe the relative amount of damage done to the pavement. The most common expression of pavement damage is the 18,000-pound equivalent single axle load. Load equivalency factors (pavement damage factors) are used to describe the relative amount of damage for a specific axle loading and axle configuration in terms of the amount of damage done to the pavement by some number of equivalent 18,000-pound axle loads. As an illustration, one application of a 12,000-pound single axle load would be expected to do an amount of damage to the pavement equivalent to 0.2 applications of one 18,000-pound single axle load. Stated another way, five applications of a 12,000-pound single axle load will do the same amount of damage to the pavement as one application of an 18,000-pound single axle load. It should be noted that the relationship between load equivalency factors (pavement damage factors) and load is not a linear relationship.

Load equivalency factors (or the number of ESALs assigned to a particular vehicle) are calibrated to specific pavement design procedures. For example, the load equivalency factors for the AASHTO Guide for Design of Pavement Structures are different from the load equivalency factors used with the Kentucky Mechanistic-Empirical Pavement Design Procedure which are different from the load equivalency factors used with the Asphalt Institute Thickness Design of Asphalt Pavements For Highways & Streets (MS-1). Also, load equivalency factors used for the design of flexible pavements (asphalt concrete) are different from the load equivalency factors used for rigid pavements (Portland cement concrete) for some pavement design procedures. For example, the load equivalency factors for the AASHTO Guide For Design of Pavement Structures include separate load equivalency factors for flexible pavements and for rigid pavements. The mechanistic-empirical pavement design procedures developed in Kentucky have been calibrated on the basis of Kentucky's load equivalency factors used for flexible pavements.

For pavement design purposes, the Division of Planning will typically provide ESALs. However, the following discussion is provided as a general description of the parameters associated with the determination of ESALs for pavement design purposes. There are various approaches which can be used to convert a mixed stream of different classifications of vehicles, different axle loads, and different axle configurations into an equivalent number of 18,000-pound single axle loads (ESAL's) and to sum these over the design period.

There are four key considerations which influence the accuracy of traffic estimates and which can significantly influence the life cycle of a pavement. These are:

1. The load equivalency factors used to estimate the relative damage induced by axle loads of different mass and configurations;

2. The accuracy of traffic volume (ADT) and weight information used to represent the actual loading projections;

3. The prediction of ESAL's over the design period; and

4. The interaction of age and traffic as it relates to the functional and structural deterioration of the pavement and related changes in pavement serviceability.

Historical Data for Forecasting Equivalent Single Axle Loads (ESAL's)

Forecasting of ESAL's is perhaps the most critical aspect of pavement design since it involves forecasting not only the growth in traffic volumes for a particular route but also forecasting the change in the characteristics of vehicles in the traffic stream. For example, during the past twenty years, there has been significant growth in traffic volumes and proportions of trucks in the traffic stream for most major routes. At the same time, the sizes and weights of trucks in the traffic stream have also increased. As a result, many pavements have deteriorated more rapidly than expected because the combination of increased traffic volumes, growth in proportions of trucks, and increases in sizes and weights of trucks. **The Division of Planning maintains historical files of this information and is best suited to apply this information for forecasting of ESAL's for pavement design purposes. Thus for purposes of this Guide, it is assumed that ESAL's will be provided.**

There may be circumstances (minor projects, approach roads, etc.) when ESAL's are not provided by the Division of Planning. For those limited conditions, the following discussion is provided to allow the designer to estimate ESAL's for purposes of pavement design:

ESAL's may be estimated from the following equation:

$$\text{ESAL's} = \text{ADT} \ x \ \text{T} \ x \ (\text{ESAL's per Truck}) \ x \ \text{DL} \ x \ 365 \ x \ \text{L}$$

where: ADT is the average daily traffic at the mid-year of the design life,

T is the percentage of trucks in the traffic stream,

ESAL's per Truck is the amount of pavement damage associated with one application of a typical truck in the traffic stream,

DL is the design life or design period in years, and

L is the proportion of the traffic in the design lane (Typically 0.5)

The Division of Planning maintains historical records of ESAL's per truck. As the size and weights and styles of trucks change, so do the typical ESAL's per truck. Following are some general guidelines for ESAL's per truck which may be used for estimating ESAL's in the absence of more definitive information from the Division of Planning.

If the Pavement Designer has only General Knowledge of the Traffic Stream

Trucks are predominately Light Trucks (delivery trucks, very few heavily loaded trucks with few overweight vehicles)

ESAL's per Truck---- 0.70 to 1.0 ESAL's per Truck

Trucks are predominately Heavy Trucks (trucks hauling aggregates, grain, steel, coal, or concrete with a significant number of overweight vehicles)

ESAL's per Truck---- 4.0 to 10 ESAL's per Truck

* 1.2 is a typical value used if no truck data is available

If the Pavement Designer has more detailed knowledge of the Traffic Stream

An Equivalent Single Axle Load (ESAL) is the measure of the amount of damage done to the pavement by one application of a single axle load (four tires) weighing 18,000 pounds. Thus, the ESAL's per truck varies dependent upon the number of axles per truck and the specific loadings on each axle or axle group. The following are typical ranges for ESAL's per truck based on assumed gross vehicle weights (GVW) and assumed distributions of loadings to the various axles or axle groups:

Single Unit Trucks

	Gross Vehicle Weight	ESAL's per Truck
Two Axles:	13,000 pounds	0.1 to 0.2
	26,000 pounds	1.1 to 1.3
	40,000 pounds	1.7 to 1.9
Three Axles:	42,000 pounds	0.8 to 1.0
	46,000 pounds	1.2 to 1.4
	50,000 pounds	2.2 to 2.4
	90,000 pounds	28.0 to 52.0
Four Axles:	66,000 pounds	1.3 to 1.5
	70,000 pounds	2.3 to 2.5
	74,000 pounds	2.7 to 2.9
	100,000 pounds	9.0 to 11.0

Semi-Trailer Combination Trucks

	Gross Vehicle Weight	ESAL's per Truck
Three Axles:	48,000 pounds	2.5 to 2.7
	56,000 pounds	2.8 to 3.0
Four Axles:	60,000 pounds	1.7 to 1.9
	64,000 pounds	2.2 to 2.4
	70,000 pounds	3.0 to 3.2
Five Axles:	80,000 pounds	1.9 to 2.1
	100,000 pounds	4.8 to 5.2
	120,000 pounds	11.0 to 13.0
Six Axles:	80,000 pounds	1.4 to 1.6
	100,000 pounds	2.2 to 2.6
	120,000 pounds	6.4 to 8.4

Automobiles

Gross Vehicle Weight	ESAL's per Auto
4,000 pounds	0.01

Catalog of Structural Designs

The following CATALOGS OF STRUCTURAL DESIGNS will be used to define the structural requirements for a given pavement section based on the CBR for the subgrade soil/rock and the forecast ESAL's for the design life. The Kentucky procedure for flexible pavement design is based on layer elastic principles. The required pavement structure layer thicknesses are determined on the basis of critical strains at the bottom of the asphalt concrete layer and top of the subgrade layer. The results of these analyses have been summarized in the form of graphical illustrations for various percentages of asphalt in the total pavement structure (33% Asphalt, 50% Asphalt, 75% Asphalt, and 100% Asphalt). There also have been computerized solutions for these analyses. However, these analyses still require the designer to apply judgement and experience in the selection of the appropriate percentage of asphalt concrete in the pavement structure. For example, what conditions are more appropriate for a 33% Asphalt design as compared with a 75% Asphalt design. Also, the mechanistic concepts used in the development of the Kentucky system are such that layer coefficients for materials varies from one percent asphalt design to another percent asphalt design. Thus, proper adjustment to a percent asphalt design not already evaluated requires a detailed elastic layer analysis. Detailed elastic layer pavement analyses are not practical for projects such as those covered by this guide.

The AASHTO Guide for Design of Pavement Structures (1993 Edition and earlier editions) is an empirical pavement design procedure. The AASHTO procedure is based on structural layer coefficients that define the structural capacity of the various layers in the pavement structure. The summation of the various layer coefficients multiplied by the thickness of each layer results in a Structural Number (SN) which is an index value defining the structural integrity of the pavement structure. This concept is much less theoretically sophisticated than mechanistic-empirical procedures such as those developed by the Asphalt Institute or the Kentucky procedure. However, the structural number concept is easily used.

The CATALOG OF STRUCTURAL NUMBERS is founded on the Kentucky procedures for design of asphalt pavements. The required pavement structures derived from the Kentucky procedures have been converted to equivalent structural numbers. These structural numbers are the required structural numbers for each specific combination of CBR and ESAL's as derived from the analyses using the Kentucky procedures. The catalog of structural numbers for flexible pavements is given in Table 2.

The CATALOG OF PCC STRUCTURAL DESIGNS has also been developed based on the AASHTO and Kentucky procedures, the thickness of Portland Cement Concrete pavement (PCC) for selected levels of ESAL's and CBR's wherein the use of PCC pavement has been historically and economically feasible are included in Table 3.

Table 2. Catalog of Flexible Pavement Structural Numbers (Based on 50% Curves)

	CBR										
ESAL'S	1	2	3	4	5	6	7	8	9	10	11
10,000	2.73	2.62	2.48	2.32	2.16	2.00	1.84	1.68	1.54	1.40	1.27
25,000	3.44	3.19	2.97	2.77	2.58	2.41	2.25	2.11	1.97	1.85	1.74
50,000	3.93	3.61	3.34	3.10	2.89	2.71	2.56	2.42	2.29	2.18	2.08
75,000	4.20	3.85	3.55	3.30	3.09	2.90	2.74	2.60	2.48	2.37	2.27
100,000	4.38	4.02	3.71	3.45	3.23	3.04	2.88	2.74	2.62	2.51	2.41
250,000	4.95	4.55	4.22	3.94	3.70	3.50	3.33	3.19	3.06	2.95	2.85
500,000	5.36	4.97	4.63	4.34	4.09	3.88	3.70	3.55	3.41	3.29	3.19
750,000	5.61	5.21	4.87	4.58	4.33	4.11	3.93	3.76	3.62	3.50	3.39
1,000,000	5.79	5.40	5.05	4.76	4.50	4.28	4.09	3.92	3.78	3.65	3.54
2,000,000	6.26	5.85	5.50	5.20	4.93	4.70	4.49	4.32	4.16	4.03	3.91
3,000,000	6.55	6.14	5.78	5.46	5.19	4.95	4.74	4.56	4.40	4.26	4.14
4,000,000	6.77	6.35	5.98	5.66	5.38	5.13	4.92	4.73	4.57	4.43	4.31
5,000,000	6.96	6.52	6.15	5.82	5.53	5.28	5.06	4.87	4.71	4.57	4.44
6,000,000	7.11	6.67	6.28	5.95	5.66	5.40	5.18	4.99	4.83	4.68	4.56
7,000,000	7.24	6.79	6.40	6.06	5.77	5.51	5.29	5.10	4.93	4.79	4.66
8,000,000	7.36	6.91	6.51	6.16	5.87	5.61	5.38	5.19	5.02	4.88	4.75
9,000,000	7.47	7.01	6.60	6.25	5.95	5.69	5.47	5.27	5.10	4.96	4.83
10,000,000	7.57	7.10	6.69	6.34	6.03	5.77	5.54	5.35	5.18	5.03	4.91
11,000,000	7.66	7.18	6.77	6.41	6.11	5.84	5.62	5.42	5.25	5.10	4.97
12,000,000	7.74	7.26	6.84	6.49	6.18	5.91	5.68	5.48	5.31	5.17	5.04
13,000,000	7.82	7.33	6.91	6.55	6.24	5.97	5.74	5.55	5.38	5.23	5.10
14,000,000	7.89	7.40	6.98	6.61	6.30	6.03	5.80	5.60	5.43	5.28	5.15
15,000,000	7.96	7.46	7.04	6.67	6.36	6.09	5.86	5.66	5.49	5.34	5.21
16,000,000	8.02	7.53	7.10	6.73	6.41	6.14	5.91	5.71	5.54	5.39	5.26
17,000,000	8.08	7.58	7.15	6.78	6.47	6.19	5.96	5.76	5.59	5.44	5.31
18,000,000	8.14	7.64	7.21	6.83	6.52	6.24	6.01	5.81	5.64	5.49	5.35
19,000,000	8.20	7.69	7.26	6.88	6.56	6.29	6.06	5.86	5.68	5.53	5.40
20,000,000	8.25	7.74	7.30	6.93	6.61	6.34	6.10	5.90	5.73	5.57	5.44

Table 3. Catalog of Required JPC Thickness (DGA Only)

	CBR										
ESAL	1	2	3	4	5	6	7	8	9	10	11
1,000,000	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
2,000,000	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
3,000,000	9.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4,000,000	9.0	9.0	9.0	9.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0
5,000,000	10.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
6,000,000	10.0	10.0	10.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
7,000,000	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0	9.0	9.0
8,000,000	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0
9,000,000	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
10,000,000	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
11,000,000	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
12,000,000	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0
13,000,000	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0
14,000,000	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0
15,000,000	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
16,000,000	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
17,000,000	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
18,000,000	12.0	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
19,000,000	12.0	12.0	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
20,000,000	12.0	12.0	12.0	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0

Table 4. Catalog of Required JPC Thickness (With Cement Treated Drainage Blanket)

	CBR										
ESAL	1	2	3	4	5	6	7	8	9	10	11
1,000,000	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
2,000,000	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
3,000,000	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4,000,000	9.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
5,000,000	9.0	9.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
6,000,000	10.0	9.0	9.0	9.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0
7,000,000	10.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	8.0	8.0	8.0
8,000,000	10.0	10.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.0
9,000,000	10.0	10.0	10.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
10,000,000	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0	9.0	9.0	9.0
11,000,000	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0	9.0
12,000,000	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.0	9.0
13,000,000	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0
14,000,000	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
15,000,000	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0
16,000,000	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0	10.0
17,000,000	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0	10.0
18,000,000	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0	10.0
19,000,000	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0
20,000,000	12.0	12.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.0	10.0

Pavement Design Computations

The required pavement design is determined on the basis of the required STRUCTURAL NUMBER. The required pavement STRUCTURAL NUMBER is determined from the CATALOG OF STRUCTURAL NUMBERS for the design CBR and design ESAL's. Required pavement thicknesses are determined using the following equation:

$$\mathbf{SN} = (\mathbf{a_1}\ x\ \mathbf{d_1}) + (\mathbf{a_2}\ x\ \mathbf{d_2}) + (\mathbf{a_3}\ x\ \mathbf{d_3}) + (\mathbf{a_4}\ x\ \mathbf{d_4}) + \ldots\ldots + (\mathbf{a_n}\ x\ \mathbf{d_n})$$

where: **SN** is the required STRUCTURAL NUMBER determined from the CATALOG OF STRUCTURAL NUMBERS

$\mathbf{a_1}$ is the structural layer coefficient for the first layer of the pavement structure, typically the asphalt surface layer for pavement designs in Kentucky. The typical layer coefficient for asphalt concrete surface courses in Kentucky is 0.44. This layer coefficient applies for all surface courses used in Kentucky except for Open Graded Friction Courses (OGFC) which are assigned no structural credit for pavement design purposes.

$\mathbf{d_1}$ is the thickness of the pavement layer corresponding to layer 1.

$\mathbf{a_2}$ is the layer coefficient for the second layer of the pavement structure, typically the asphalt concrete binder layer or asphalt concrete base layers for pavement designs in Kentucky. The typical layer coefficient for asphalt concrete binder courses in Kentucky is 0.42. The typical layer coefficient for asphalt concrete base courses in Kentucky is 0.40.

$\mathbf{d_2}$ is the thickness of the pavement layer corresponding to layer 2.

$\mathbf{a_3}$ is the structural layer coefficient for the aggregate base layer of the pavement structure. The typical layer coefficient for aggregate base layers in Kentucky is 0.14.

$\mathbf{d_3}$ is the thickness of the pavement layer corresponding to layer 3.

$\mathbf{a_4}$ is the structural layer coefficient for chemically modified roadbed soils. Typical layer coefficients used for chemically modified roadbeds in the design of pavements in Kentucky are 0.08 to 0.10. These are based on the assumption that chemical modification increases the CBR of the soil to a value greater than a CBR 6.

$\mathbf{d_4}$ is the thickness of the pavement layer corresponding to layer 4.

Typical values for structural layer coefficients are:

Asphalt Surface--	0.44
Asphalt Binder--	0.42
Asphalt Base--	0.40
DGA base and Crushed Stone Base	0.14
Lime/Cement Modified Roadbed	0.11
Rock Roadbed	0.08

Structural layer coefficients for other materials typically used in Kentucky are:

Mechanically Modified Roadbed--	0.07
Aggregate Drainage Blanket--	0.14
Asphalt Treated Drainage Blanket--	0.21
Cement treated Drainage Blanket--	0.21

*** In no case should the new pavement structure have a lower structural number than the existing pavement adjacent to the project.*

Shoulder Design

Pavement shoulders should be designed to meet appropriate geometric criteria. Thickness should be determined to insure adequate structural support is provided to meet any anticipated shoulder traffic. Typically shoulders should be designed to accommodate a minimum of 20% of the mainline ESAL's. This generally correlates to carrying the top asphalt base and surface courses onto the shoulder with full-depth DGA below. In situations where earth shoulders would be warranted, it may be necessary to provide an additional 2 feet of full depth pavement to insure adequate edge support.

NOTE: Paved shoulders less than 4 feet in width should use the same asphalt mix types shown on the driving lanes.

Pavement Drainage & Aggregate Base Selection

Adequate drainage should be provided to the pavement structure to insure a successful pavement service life is achieved. Various types of pavement drainage systems have been utilized throughout Kentucky. For pavements designed using this guide the following criteria should be utilized:

Design ESAL's	
Less than 1,000,000 ESAL's	DGA or Crushed Stone Base
1,000,000 – 5,000,000 ESAL's	Daylighted (or piped) Crushed Stone Base
5,000,001 - 20,000,000 ESAL's	DGA, Drainage Blanket and Piping System

Development of Alternate Pavement Designs

The equation for STRUCTURAL NUMBER (SN) indicates that there are an infinite number of combinations of layers of the various paving materials that will satisfy the STRUCTURAL NUMBER requirement specified in the CATALOG OF STRUCTURAL NUMBERS. The number of potential solutions is reduced somewhat when considering the practical limitations of placing the various pavement layers. The layer thickness ranges of common paving materials in Kentucky are:

Asphalt Surface, 0.38-in nom/max--	1.25 inches per course
Asphalt Binder, 0.5-in nom/max--	1.5 to 2.0 inches per course
Asphalt Base, 0.75-in nom/max--	2.25 to 3.5 inches per course
Asphalt Base, 1.0-in nom/max--	3.0 to 4.5 inches per course
Asphalt Base, 1.5-in nom/max--	4.5 to 5.0 inches per course
Aggregate Base (DGA or CSB)--	4.0 to 6.0 inches per course
Aggregate (Untreated) Drainage Blanket--	4.0 to 6.0 inches per course
Asphalt Treated Drainage Blanket--	4.0 to 6.0 inches per course
Chemically Modified Roadbed--	8.0 to 12.0 inches per course

Refer to Appendix D for more detailed discussion on the use of Asphalt paving materials.

From a pavement engineering perspective, there are some variations in proportions of paving materials which are better suited to specific engineering applications that others. For example, pavement structures with thick aggregate bases (33% to 50% asphalt concrete) typically would be expected to provide better performance over soil subgrades with low CBRs (<3), with the water table close to the surface or where the soils are known to be highly moisture sensitive. Conversely, pavement structures with thick asphalt layers typically will provide better performance over rock roadbeds, chemically modified roadbeds, or soils with higher CBRs ($\geq$3).

Development of alternate pavement designs should typically involve a “maximum aggregate” design, a “maximum asphalt concrete” design (utilizing 4-inches of aggregate base), and a Portland cement concrete design for comparative analyses. Other alternate pavement designs should be considered where specific project considerations indicate a need. Each alternate considered should meet or exceed Structural Number requirements identified in the CATALOG OF STRUCTURAL NUMBERS.

Comparison of Alternate Pavement Designs

The positive and negative engineering aspects of each alternate pavement design must be evaluated. Principal considerations include the characteristics of the traffic stream, characteristics of the subgrade, construction phasing, climatic and other environmental considerations, recycling considerations, and economic considerations. Secondary considerations include performance of similar pavements in the area, adjacent existing pavements, conservation of materials and energy, the availability of local materials or contractor capabilities, traffic safety and maintenance of traffic during construction considerations, incorporation of experimental features, stimulation of competition, and the preferences of local municipalities or the recognition of local industries.

Selection of the Best Pavement Design

Selection of the best pavement design for a given project is a combination of engineering judgement, experience, and economic analyses. Generally, pavement design alternates not satisfying project specific engineering considerations should first be eliminated. Thereafter, the primary and secondary considerations discussed above should be used to eliminate other alternate pavement designs being considered. Economic analyses should be used as the final determination of the best alternate pavement design if all other considerations are equal. Economic analyses should be developed on the basis of initial construction costs only for projects having design ESAL's less than 1,000,000. For projects having design ESAL's greater than 1,000,000 a life cycle cost analysis should be performed.

Life Cycle Cost Analysis

The Life Cycle Cost Analysis will include the analysis of both initial construction costs and rehabilitation costs at selected intervals over an analysis period of 40 years. In addition, user costs will be considered at various levels based on the design ESAL of the project. Material costs will be determined based on values obtained from the Engineering Estimating Section in the Division of Construction Procurement. For projects that do not meet the criteria listed in the Pavement Type Selection Policy (Appendix F) material costs may be estimated from the latest Average Unit Bid Prices list. The rehabilitation scenarios presented may not reflect the actual rehabilitation schedule for a specific pavement. However, they do provide a good estimation of the cost associated with maintaining a pavement structure for 40 years. The Pavement Design Excel spreadsheet is available to assist in conducting the life cycle cost calculations. Specific inputs to this procedure are as follows:

Analysis Period: 40 years

Rehabilitation Scenarios:

Flexible Pavements

Rehabilitation 1, Year 15
Mill 1.25" – 1.25" Overlay (Driving Lanes)

Rehabilitation 2, Year 30
Mill 1.25" – 3.25" Overlay (Driving Lanes)

Portland Cement Concrete Pavements

Rehabilitation 1, Year 25
Repair 5% of driving lane total area
Diamond Grind (Driving Lanes)

User Costs:

Less Than 5,000,000 ESAL's	No user cost, initial cost only
5,000,000 - 10,000,000 ESAL's	$1,000/day
10,000,001 - 15,000,000 ESAL's	$2,000/day
15,000,001 - 20,000,000 ESAL's	$3,000/day

Length of Construction

Initial Construction: 120 days
Rehabilitation: 30 days

Submittals and Approvals

All pavement designs *shall* be submitted to the Pavement Branch in the Division of Highway Design.

There will be two sets of criteria for the process of submitting and approving pavement designs. These criteria and procedures are as follows:

5,000,000 ESAL's or Less & Less than 1 Mile in Length
These designs **Do Not** need to be approved by Central Office staff. The District Branch Manager for Pre-construction shall approve these designs, excepting for pavement designs involving PCC pavement. Approval of pavement type selection (selection of PCC pavement compared with asphalt pavement for this level of traffic) must be approved by the Branch Manager for Pavement in the Division of Highway Design. Pavement designs prepared by a Consulting Engineering Firm must be prepared by a Professional Engineer Licensed in Kentucky and submitted to the District for approval. Designs are to be submitted to Central Office Pavement Design for archival, pavement management purposes and for review of pavement type selection justification. Documentation and justification supporting the selection of a specific pavement type (Asphalt vs. JPC) is to be included in the submittal to the Central Office. Central Office Staff will be allowed 15 working days to review and comment on pavement type selection justification. Following this review period, comments will be returned to the District regarding the appropriateness of the selected pavement type. While these designs will not need to be approved by the Central Office, the designs will be reviewed to insure proper implementation of this guide. If any errors are found during this review they will be noted and returned to the district for correction.

The Project Manager will be responsible for distribution of the approved pavement design for these projects. The distribution list includes the Project Management Coordinators, Plan Processing Review, and the consultant, if necessary.

Greater Than 5,000,000 ESAL's or 1 Mile in Length or Longer
These designs *shall* be submitted to the Pavement Design Branch of the Division of Highway Design for approval. These designs are to be submitted by the Project Manager to Central Office Pavement Design. The Branch Manager for Pavements in the Division of Highway Design must approve these designs. Pavement designs submitted to the Cabinet by a Consulting Engineering firm must be signed by a Professional Engineer Licensed in Kentucky. Approval by the Central Office Pavement Staff is intended to verify implementation and justification for pavement type selection.

The Pavement Branch staff in the Division of Highway Design will be responsible for distribution of the approved pavement design for these projects. The distribution list includes the Project Management Coordinator, Plan Processing Review, and the consultant, if necessary.

NOTE: The Project Manager will be responsible for submitting an updated and approved pavement design when final plans are submitted to the Central Office.

PAVEMENT DESIGN SUBMITTAL FOLDER

All pavement designs will be submitted to the Pavement Branch of the Division of Highway Design. The cover sheet for this submittal is attached to this document. The cover letter will identify the project information and a summary of the pavement design type selection. The cover letter will also show a checklist of what documentation is included in the submittal. The following items should be included:

1) Design Executive Summary
2) Pavement Design (TC 61-29)
3) Design Calculations
4) **Type Selection Justification**
5) Geotechnical Information *
6) Traffic Information *
7) Typical Sections and Details
8) Special Notes and Provisions
9) Other Documentation

* If available

Pavement Design Submittals including all of the above information should be stapled together for submittal to the Central Office Pavement Design Branch. Examples of pavement designs are presented in Appendix A. Typically used Special Notes and Special Provisions are included in Appendix B. General pavement design notes are included in Appendix C. The pavement design submittal cover sheet and submittal forms are presented in Appendix D. There are electronic copies of these two forms on the KYTC web page under the Division of Highway Design.

The Division of Highway Design Pavement Branch will post periodic updates of all applicable notes and provisions to the Highway Design web site.

TECHNICAL ASSISTANCE

Staff from the Division of Highway Design will be available to provide assistance to roadway designers for application and implementation of these guidelines.

Tel. (502) 564-3280

PAVEMENT DESIGN SPREADSHEET

The Pavement Design Spreadsheet is available in Microsoft Excel format on the Division of Design homepage at http://transportation.ky.gov/design/design.asp. This page will maintain the most current version of the spreadsheet for use on all pavement designs.